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A Cognitive Model of Pedagogical Question Asking

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Technologies for Skill Acquisition and Retention Technical Area
Training Research Laboratory



U. S. Army

Research Institute for the Behavioral and Social Sciences

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<p>Soldiers will be interacting more directly with high-technology, computer-based training systems in the Army of the future. Soldier trainees interacting with these machines will profit from the ability to ask questions as they learn. A fundamental problem we need to address is how to create computer-based tutorial dialogues that will allow soldiers training on these systems to ask questions easily and naturally. The first step toward creating interactive tutorial dialogues is to understand the cognitive role of pedagogical question asking in a computer-based learning environment. Questions asked during acquisition of a complex skill reflect the information military students require at different stages of learning. Evaluation of the kinds of questions asked in a particular MOS should provide information descriptive of each student's current knowledge state. Question analysis can be used for defining the goals, operators, and methods a student is using or needs at a given time during the instructional sequence. Mapping the questions asked at</p> <p style="text-align: right;">(continued)</p>				
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a particular point during the acquisition process onto the conceptual representation for the MOS will indicate what kind of knowledge is being processed by a student. As new material becomes learned and organized in the knowledge representation, patterns of knowledge should shift from one area of the representation to another. This report describes a cognitive model that addresses the problem of understanding the role of question asking in skill acquisition.

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FOREWORD

The Army needs to develop intelligent training systems with sophisticated soldier-machine tutorial dialogue interfaces so that human interaction with these systems is facilitated. One step toward this goal is to investigate the nature of question asking in tutorial exchanges. Researchers need to understand how this linguistic system is used by military trainees to obtain information they need to know during instruction. Articulating what a trainee does not know through question asking may be useful for developing student modeling techniques and adaptive instruction in intelligent training systems. Additionally, application of this research to military domains that utilize question asking, such as in military intelligence, may improve training in these MOS. Only with a well-developed theoretical basis for question asking can research for developing soldier-machine tutorial dialogue interfaces continue.



EDGAR M. JOHNSON
Technical Director

A COGNITIVE MODEL OF PEDAGOGICAL QUESTION ASKING

EXECUTIVE SUMMARY

Requirement:

The U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) conducts research in support of new technologies for Army training. One area of research is that of developing computer training systems with soldier-machine tutorial interfaces with natural language capability. This report describing a theory of pedagogical question asking provides a cognitive basis for future research in this area.

Procedure:

The author of this report describes a cognitive theory of pedagogical question asking in a learning-by-doing paradigm based on a spreading activation memory framework. This theory is part of an in-house research effort investigating the natural language requirements in tutorial dialogues for military training systems.

Findings:

Pedagogical questions function according to specific conversational rules in order to obtain instructional information for the learner. Questions function as probes in memory to focus activation of the knowledge being processed at the time a question is posed. Further functions for these questions include articulating discrimination and generalization learning of the knowledge.

Utilization of Findings:

The purpose of this report is to describe a theoretical model of pedagogical question asking. Subsequent planned research will assess the usefulness of this model for describing soldier trainees' knowledge states during computer-based learning. A target domain, the 97E military interrogator, will explore the usefulness of this model for training question asking skills in foreign languages.

A COGNITIVE MODEL OF PEDAGOGICAL QUESTION ASKING

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A COGNITIVE MODEL OF PEDAGOGICAL QUESTION ASKING

INTRODUCTION

Question asking is an integral part of instruction. Military students will often ask questions to help them comprehend what they are learning. As an instructional strategy, question asking has received attention in the research community (Collins, Brown & Newman, 1987; Palincsar & Brown, 1984), but very little work has been done examining the cognitive aspects of student question asking. The study of question asking may have important consequences for understanding the kinds of knowledge a student needs and when during skill acquisition. Moreover, pedagogical questions may reflect how students are reasoning about (Norman, 1982) and organizing the knowledge.

The use of questioning in a tutorial dialogue dates back to Socrates who believed that the appropriate question, when posed to the student, would cause the student to "remember" the correct response. He believed that we possess all the knowledge of the world in our minds, but don't always have access to this knowledge. "If someone will keep asking the student these same questions often and in various forms, you can be sure that in the end he will know about them as accurately as anybody" (Plato, 1924). Following the Socratic method, question asking by the tutor serves to refine and modify the student's knowledge structure by referring to the underlying causal model for the domain. Tutor-generated questions are generally intended to evaluate what the student knows about the domain by requesting that the student provide a response. Through the mechanism of tutorial question asking, responding, and tutorial explanation, the student will eventually acquire what it is he or she needs to know from the instruction presented.

However, tutorial dialogues which enable reciprocal communication also include student-generated questions. Question asking by students can serve as a self-directed monitor during instruction to guide acquisition of the knowledge and to request instructional information that is necessary for the correct encoding, organization, and comprehension of the knowledge. The work addressed here will focus on the function of student questioning in tutorial dialogues and how the questions serve to monitor the student's cognitive processes and reflect their reasoning about the knowledge during skill acquisition. The domain used to discuss the question model is Lotus 1-2-3, a procedural computer command language; the instructional context is a tutorial dialogue to guide computer-based learning by doing.

Pedagogical question asking is based upon the following premises. First, there is a unique question system that functions in a specialized manner in pedagogy. Secondly, within this system, student-generated questions function to aid the student in understanding new knowledge (Brown & DeLoache, 1978; Bransford, 1979; Collins, 1977). And finally, the ability of a student to articulate questions during learning is based on the availability and knowledge appropriate structures in memory (Miyake & Norman, 1979). Furthermore, evidence exists (Chi & Glaser, 1980; Swartz, 1987) that novices do in fact ask many questions when learning a new skill, even if knowledge appropriate structures are not yet formed.

The cognitive processes underlying the proposed model of pedagogical question asking are based on the theory of spreading activation. To begin, I will argue that pedagogical questions reflect in part self-directed probes in memory which function as a control mechanism for focusing activation at a particular knowledge node and maintaining this information in working memory during processing. In articulating a question the student has searched memory for the requisite information, found it was not available, and evaluated a requirement for asking a question to obtain what is needed for understanding or to perform some activity in the task environment. Secondly, I claim that pedagogical questions function as organizers for the knowledge through discrimination and generalization processes as students evaluate what they know with the feedback received from tutorial responses and task goal end states.

The kinds of questions asked in a particular domain or military occupational specialty (MOS) should provide information that is descriptive of a student's current knowledge. Question analysis can be used for defining the MOS-specific goals, operators, and methods a student is using or needs at a given time during the instructional sequence. Mapping the questions asked at a particular point during the acquisition process onto the conceptual representation for the domain should indicate what kind of knowledge is being processed by a student. Using a spreading activation mechanism as the framework for accessing the developing domain representation, we should be able to take these mapped questions and derive knowledge state activation patterns for a given point in time. As new material becomes instantiated and organized in the student's internal representation, these patterns should shift from one area of the network to another. This knowledge state information may have potential for facilitating the development of tutorial dialogues and ultimately instructional delivery in computer-based learning by providing a more clear understanding of what information the student is requesting and processing at the time a question is asked.

This paper describes a cognitive model of the processes that underlie student pedagogical questions. Subsequent reports will provide empirical data in support of the model presented here. I will begin with a description of the structure of the pedagogical question system. The next section will outline the theoretical basis of question asking. I will present a cognitive model of question asking and illustrate how questions are used by students for metacognitive control to focus activation in the developing representation and how these same questions reflect a discrimination and generalization learning function. The last section will discuss how this model can be used for deriving knowledge state activation patterns and the potential role this may have for student modeling in the development of computer-based tutorial dialogue interfaces in military training systems.

THE PEDAGOGICAL QUESTION SYSTEM

Specialized language subsystems exist within human communication which enable us to exchange information in a particular manner. For example: formal debate, rhetoric, and question asking. Each subsystem communicates information in specialized ways for the particular purpose of the system. The formal debate subsystem uses communication rules which foster organized argumentation between individuals to defend or attack a given proposition.

Rhetoric employs language to persuasively influence the thoughts and actions of others. Question asking functions as an expression of inquiry that invites a response or casts doubt on some piece of information. The question subsystem, one of the many specialized subsystems in human communication, is subject to its own unique set of linguistic, contextual, and usage rules to achieve its communicative purpose.

The General Question System

Searle (1969) defines a question as a special case of request. He distinguishes between 'real' questions that request information and 'test' questions that request that the hearer provide information. Belnap and Steel (1976) believe that a question makes an implicit request regarding an answer the respondent is to provide. Harrah (1973) refers to 'standard' questions in pedagogy in which the questioner knows what the problem is and how to articulate a question in order to receive an appropriate response. Questions can also be speech acts that cast doubt, however, I will not include this type of question in the discussion of this system. Each of these definitions hold subtle nuances in meaning and the reader can appreciate why the development of a psychological model of question asking remains a challenging task. Here I use the notion of a 'real' question as being uttered with a goal of requesting information. Rhetorical questions, questions which cast doubt, and questions whose motivations are governed by other factors other than obtaining information will not be considered. A question can be thought of as a special case of proposition. In question utterances a proposition is expressed, however, with some of the propositional contents missing. The interrogative pronoun in this question can be thought of as an anaphoric referent (Searle, 1969; Grice, 1975; Belnap & Steel, 1976) to these missing elements.

As a framework in which these questions function, I propose five general principles: 1) to obtain information through inquiry, 2) for each question there exists an appropriate response, 3) questions identify problems, 4) question form must be appropriate for the domain, and 5) the intent of the question must be understood. These principles are discussed in the next section, however, their use to structure the question-answer exchange may vary between domains. The following provide two examples of how question subsystems function differently.

In military interrogation, the question system plays a major role in obtaining information from a source during the interrogation process. This communication exchange is highly controlled and manipulated by the military interrogator. The interrogator poses carefully constructed questions designed to elicit and verify specific responses from the prisoner (source). The prisoner is not allowed to ask questions of the interrogator. Often prisoners are recalcitrant and unreliable respondents. Therefore, the military interrogator must decide upon a certain approach to use in the questioning phase of the interrogation. This approach technique and the ways in which the question system is manipulated to extract information from the source are unique to this domain. In military interrogation the interrogator exercises complete control of the communication function of the question system, thus violating Grice's (1975) cooperative conversation principles.

In medical diagnosis, the question system operates quite differently with a more cooperative exchange occurring. The physician poses the questions to the patient with the purpose of obtaining symptomatic information that will lead the physician to identifying the correct medical diagnosis. The questions asked are formulated to test certain hypotheses which are either confirmed or disconfirmed on receipt of the patient response. The questioning sequence adapts to the cumulative effect of the symptomatic information provided by the patient and new questions generating new hypotheses will be asked if medically warranted. When the physician has evaluated and tested all plausible hypotheses and feels certain of a diagnosis, the questioning process terminates. While the physician has control over the questions asked, his or her motivation for questioning is different than that of the military interrogator.

In a pedagogical domain, the question system operates in yet another manner than the two examples cited above. The following discussion will provide a basis for understanding how a specialization in pedagogy effects the general principles by which the system operates.

Specialization of the Question System in Pedagogy

In the pedagogical question system, the main purpose of student question asking is to obtain and process instructional information. In this system, basic pedagogical questions will be similar to those defined by Searle, real (student) and test (tutor) questions. Who obtains the information through questioning, the tutor or the student, will affect the functional mechanism by which questions operate. Harrah (1973) calls for a theory of pedagogical questions that would encompass both 'standard' questions (Searle's real question) and test questions (Searle's test question) in the pedagogical question system. The test question is that which the tutor poses in order to evaluate what the student knows or how well certain concepts are understood. Traditionally, researchers and educators have concentrated on studying this kind of questioning in pedagogy. I will focus primarily on the function of standard or 'real' student questions in the discussion of the question principles and question system in pedagogy. In order to understand how the pedagogical question system functions, we must describe the special conditions surrounding the five question asking principles, certain operational features unique for students using the system, and the predictable violations that occur quite readily in pedagogy.

Principle 1: Obtaining Information Through Inquiry

In the general question system, the individual who wants to get some type of information poses a question intended to solicit some response. This fundamental principle is based on the assumption of cooperative communication (Grice, 1975). I assume the same cooperative exchange in the pedagogy wherein those involved in the tutorial dialogue (student and tutor) communicate freely for instructional purposes. Generally, there are no obvious violations of this principle in pedagogy. Evidence exists that novice students generally ask a lot of questions (Chi & Glaser, 1980) and that some of these questions are used to familiarize the student with the situation (McKoe, 1982) before making requests to obtain specific information related to a given task problem. Thus we can expect this principle to apply often in

the early stages of skill acquisition and throughout learning as instructional information is requested. Students will ask questions to obtain specific kinds of information to verify facts, test hypotheses, complete understanding of specified details, instantiate a particular procedure or establish causal relationships as the subject matter is learned.

Several presuppositions for asking a pedagogical question under this principle are that the speaker, a student, believes a response exists, knows what problem exists, and can articulate an interrogative phrase in a certain form that will obtain the requisite information to solve the problem. These presuppositions can be explained by the remaining principles extant in the pedagogical question system

Principle 2: For Each Question There Exists an Appropriate Response

Questions operate under the principle for obtaining information with an implicit belief by the speaker that a response exists. This second principle is based on the assumption that a speaker will most likely ask a question when he or she believes a response is available. The topic of delivering appropriate responses to questions has been the focus of much research in artificial intelligence (McKoeun, 1982; Mays, Joshi, & Webber, 1985; Pollack, 1985). Mays *et al* summarize several pertinent issues in response behavior which may effect the validation of this principle. Responses may provide more information than is literally requested, justify or explain an answer, correct misconceptions reflected from the query, and explain about the structure and content of the domain knowledge. Thus appropriateness of response implies that it address the true intent of the question. In pedagogy the tutor's response to student questions will play an important role in guiding the student's learning. These response behavior issues raise many problems in deciding on the appropriateness of an instructional response. How to solve the problems mentioned above remains as yet unknown although many researchers are actively addressing this topic.

In a pedagogical setting, either the student or the tutor will be the respondent depending on who asks the question. If the respondent is believed by the speaker to be able to deliver an appropriate response, then the speaker will be more inclined to pose a question. In the ideal environment with both the student and teacher participating as speaker-respondent in the pedagogical question system, there is no reason why an appropriate answer should not be available from the tutor as respondent. We assume that the tutor knows the domain well and also how to answer a variety of student questions. Indeed, the student as questioner implies his or her trust in the assumption that the tutor will be capable of answering the question with an appropriate instructional response. Thus in the case of student question asking, we don't expect any violations of this principle. However, when the tutor poses the question, the student, who does not possess the expert knowledge representation for the domain, may have difficulty in providing an answer. Thus, in the case of tutor question asking we can expect common violations of this principle by the student. In fact, certain types of these violations in defined domains should be predictive when memory processing constraints and level of learning are taken into account. Students may commit errors, forget knowledge, develop misconceptions about what they are learning; all of which will affect their responses to tutor-generated questions.

Principle 3: Problems Must be Identified to Ask a Question

To ask a question the questioner must need the requested information. A presupposition for asking a question under this principle is that the speaker knows what problem exists and can articulate a question that will obtain the requisite information to solve the problem (Harrah, 1973). The question itself points to what the student believes the problem to be. Improperly identified problems, however, will affect the utility of the question for soliciting the appropriate response and guiding subsequent comprehension processes. In the pedagogical setting, the problem identified is usually a lack of adequate domain knowledge or a misunderstanding about some piece of instructional information. A basic assumption here is that if no problem is identified then no question is necessary.

This principle is violated when the student misidentifies the problem. These difficulties are most prevalent at the beginning stages of learning. Although students know that they do not know what they need to know, they may not be able to precisely locate the task-appropriate problem to facilitate their understanding. Thus their questions may not be useful for the problem at hand. We can anticipate that the student will certainly be able to identify problems and thus the basic premise of this principle will not be violated. However, recognizing students' incorrectly identified problems is important for delivering appropriate responses, tutorial remediation, and instructing the students in the correct use of the question system in pedagogy.

Principle 4: Question Form Must be Appropriate to the Domain

In a given situation, a questioner will identify the need to obtain some information in order to solve some problem. He or she must then articulate the question in a form appropriate for obtaining the requested information. The ability to articulate such a question assumes that the questioner is familiar with the domain or with the situation. Similarly, that enough requisite knowledge is available that will permit the questioner to evaluate any potential problem and subsequently pose a question if further information is required. In pedagogy, this principle will often be violated, especially in the early stages of learning.

Novices have difficulty generating questions of the appropriate form because they lack domain-specific knowledge (Miyake & Norman, 1979). Students will always be able to identify problems even if they involve certain misconceptions about the domain or misidentify the appropriate problem. However, the ability to articulate questions in a form which correctly identifies what it is the student wants to know is not always easy. Often questions will be vague and full of anaphoric and ambiguous reference as students attempt to articulate a question. Violations of this principle will effect the basic communicative purpose of the question system. Students who are unable to articulate a question of the correct form will risk confusing the intent of their question and impede receiving the needed instructional response. Yet, in pedagogy, the "ideal" tutor is mindful of such violations and can compensate for ill-formed questions by heuristic interpretation of the question, what is perceived by the tutor as the intent of the question, and the instructional context. Indeed, it is under this principle that much

instructional tutoring may occur. For example, in reciprocal teaching (Palincsar & Brown, 1984) students are taught how to articulate questions of the correct form in order to help improve their reading comprehension strategies.

Principle 5: Intent of the Question Must be Understood

In the pedagogical question system, this principle is violated somewhat less frequently on the part of the tutor as respondent, a domain expert with all of the requisite knowledge available for tutoring the subject matter. As subject matter expert and one who presumably knows the domain knowledge as well as student reactions, responses, and common misconceptions during learning, the tutor should for the most part be able to interpret the intent of even the most poorly articulated student question. Admittedly, this places a heavy burden on the tutor. Nevertheless, as in general discourse processing, intent may be misunderstood and a clarification dialogue between tutor and student may be initiated to facilitate identification of the true intent of a student question. The intent of a particular question requires that the respondent appropriately interpret the question. If the intent is not understood because the student failed to articulate a question of the appropriate form given a certain problem, then principles three and four above may have been violated. If the intent of the question is misunderstood because the tutor failed to correctly interpret an appropriately articulated question, then this principle will be violated.

Interpretation of question intent depends on several linguistic factors: semantics, pragmatics, and context. Without considering all of these elements, the intent of the question may be misinterpreted. Discourse processing and topic intention in topic research (Graesser & Black, 1984; Robertson, Black & Johnson, 1981; Grimes, 1975) have investigated the complexities involved in accurately interpreting intention in discourse. This problem is a difficult one, yet crucial to the respondent's ability to provide an appropriate response to the student's question and to enable a cooperative exchange.

Summary

Several predictable violations of these principles occur in the question system in pedagogy. Students will make errors identifying problems, develop misconceptions, and pose poorly articulated questions during learning. The enlightened tutor, aware of these possible violations, can be better prepared to engage in meaningful exchanges with the student during instruction. Recognition and understanding of these violations are requisite to good tutoring and may also foster instructional approaches to guide the student toward better use of these communication systems during learning. Indeed several researchers are exploring this type of approach to learning (Collins, Brown, & Newman 1987; Palincsar & Brown, 1984). With this background, we can now proceed to a discussion of the theoretical framework for the psychological processes underlying the function of this question system during learning.

PEDAGOGICAL QUESTIONS FOR METACOGNITIVE CONTROL

Metacognition is a higher-order process we employ to guide various lower level processes. Bransford (1979) believes that metacognition requires assessing the current state of our knowledge. The notion he alludes to is that as we monitor our cognitive activities, we somehow evaluate current states through checking, verification, and testing of the concepts and skills presented to us in our daily experiences with what we know or have stored in memory. I argue that student question asking articulates these monitoring processes during skill acquisition. Brown and DeLoache (1978) discuss the basic skills of metacognition used to control learning and problem solving as: predicting consequences of actions and events, checking results of our own actions (did it work), monitoring one's ongoing activity (how am I doing), reality testing (does this make sense). After all but one of the basic skills they present, a self-directed question was placed in parentheses indicating that questioning is a naturally occurring metacognitive process we employ to monitor our cognitive activities. We can easily imagine a question, 'Will it work?' after the first skill Brown and DeLoache list to monitor predicting consequences of actions and events.

Feedback is essential for evaluating our knowledge of the world and ongoing cognition. Without feedback we would have nothing with which to compare our current knowledge state. It is this information which can serve as the stimulus for our asking a question and provide a state condition we can use to match against what we have stored in our own internal representations in memory. In computer-based learning, there are two main feedback sources, instructional and environmental, that we might use to evaluate current knowledge states.

Memory retrieval is the mechanism used to access what we know as we compare these feedback sources with what is being learned. This process involves certain steps the learner undergoes as he or she monitors what is being learned: 1) an item or probe is presented and encoded, 2) a search process is then begun attempting to match the probe with associated knowledge in memory, and 3) a decision occurs when a match for the probe is made. It is when a match cannot be made that provides the condition for question asking. In a computer-based learning by doing environment, probes can be either the current task subgoal condition or system feedback. If the decision response is 'yes' to the match of the probe with the desired knowledge stored in memory, an action can be initiated by the student. If the decision is 'no' the student can make a judgement about what he or she needs to have access to, and ask a question, assuming the learning environment included a tutorial dialogue capability.

Once the knowledge structure is accessed in memory, pedagogical questions can function to help build and generate a more complete domain representation. The working hypotheses for the kinds of pedagogical questions students ask as they monitor learning are that: 1) the number of questions asked will change in relation to the amount of practice and feedback a student has received; and 2) the kind of question asked will change in relation to the amount of practice and feedback a student has received. The first working hypothesis is based on findings that support the notion that more questioning occurs in the early stages of learning (Chi & Glaser, 1980) or when the task

presented to the student is novel. The last working hypothesis is based on the argument put forth by Miyake and Norman (1979) who stated that the ability to ask questions is based on the level of completeness of a student's internal representation for the knowledge. Thus as a student's internal representation acquires more structure and completeness, the type of questions asked should reflect the new information and change accordingly. The author is preparing a report that presents empirical data to test these hypotheses (Swartz, in preparation_b).

The memory framework in which pedagogical questions access current levels of understanding is a spreading activation mechanism. Two basic functions for the questions are proposed: 1) to focus activation in a particular location of the knowledge representation and maintain this information in working memory during processing, and 2) to organize and structure the knowledge through discrimination and generalization processes. Activation initiated by question asking will regulate flow of activation within the knowledge structure that is accessed during processing. Discrimination and generalization processes, articulated through question asking as various end states are compared and evaluated with what is being learned, will serve to monitor acquisition and organization of the knowledge. Strengthening processes will be reinforced through additional questions and repeated performance in similar states as practice continues.

In discussing the framework for this model, it is necessary to make some structural assumptions about how the knowledge is represented in memory. The particular domain considered is a procedural skill, the command language Lotus 1-2-3. While the human representational system in memory is far from understood, frameworks for both declarative and procedural knowledge have been proposed (Collins & Loftus, 1975; Anderson, 1983a). I assume a hierarchical goal-based semantic network for the domain in order to facilitate discussion of the question asking processes hypothesized as a function of the operating pedagogical question system. Thus, the proposed conceptual network for the domain will include concept nodes for both declarative and procedural knowledge (I have separated these two knowledge types in the conceptual representation that was used to deliver tutorial instruction and which is presented later). This seems plausible when we consider that learning in any new domain begins declaratively (Anderson, 1983a) with lower order components of the knowledge (Hayes-Roth, 1977) that develop and strengthen themselves in the representation with practice and continued learning. Thus we might consider the concept nodes for procedural knowledge in the conceptual representation as a type of lower order declarative component before the actual skill is acquired. As learning progresses, a new structure for the procedural knowledge will be created and stored in memory.

A network representation for the knowledge similar to the Collins and Loftus model (1975) is assumed which groups together concepts in the domain. The concept nodes are linked to subordinate nodes which further define the superordinate node concept. Links carry relational meaning between the concept nodes which are defined by the nature of the domain (procedural, goal, causal, property/attribute are examples for procedural command language domains such as Lotus 1-2-3). Other link and node types may be created during learning as the student gains experience and more detailed knowledge through

practice and question asking. The procedural concept nodes in this declarative network can be thought of as pointers to another knowledge structure located elsewhere in long-term memory (LTM) that will develop as the domain procedures are learned. Understanding how these question asking processes access and instantiate the knowledge in memory will permit us to examine more closely how the knowledge is located, transformed, and used to modify the developing domain representation during skill acquisition.

Spreading Activation Framework for Question Probes

The framework discussed here follows Anderson's (1983b) model of spreading activation. Sources of activation can come from a variety of origins. In a computer-based learning by doing paradigm the most obvious source of activation is the task goal the student encounters. This is very similar to Anderson (1983a) who believes that current task goals serve as constant sources of activation. However, if the source is not focused on, the activation effect will eventually decrement. On the other hand, if some other element maintains activation and provides focus on a particular knowledge node, then activation will remain constant. Student-generated questions as probes in memory serve this focusing function. They identify the locus of the missing knowledge in the internal representation and can sustain activation of a particular knowledge node and its associated elements. This focusing function will serve to keep the activated node in working memory (WM) for processing as the student either receives and processes a response to the question or continues to apply problem solving strategies to the current task subgoal.

Questions to Focus and Maintain Activation

Lachman, Lachman, and Butterfield (1979) believe that when a person needs a particular piece of information, he or she attempts to retrieve it directly from memory. I will argue that student questions can serve a control function to activate the domain network in the area accessed in a failed attempt at retrieval of the information required during learning. Questions as probes in memory can control the spreading activation mechanism that is triggered automatically by the constant source of activation emanating from the task subgoal and shift the focus to other areas of the network.

Any question can serve this function as long as the knowledge asked about pertains to the instructional domain. Therefore, 'Is this right?' is a verification question that does not refer to any knowledge-specific information in the developing internal representation and doesn't function to focus activation in the network. Rather, questions of this sort are more true metacognitive monitors for checking results of one's actions (Brown & DeLoache, 1978). Similarly, 'How can this be right?' might be most appropriately interpreted as a metacognitive question even though causal or explanatory responses might result were the question to receive a response.

Following tutorial instruction where all of the information in the conceptual representation has been presented, a student then engages in a practice exercise. To illustrate this focusing function, we can consider a student who is trying to erase some data from the computer screen in a Lotus 1-2-3 exercise. The student, in response to the task subgoal as the primary

source of activation, is unable to retrieve the appropriate method from memory as various problem solving strategies are attempted and asks a question:

How can I erase that cell?

By identifying the knowledge node in the question, we assume that the 'erasing' node has been activated in the student's internal representation. Editing is a super class node for several operators and methods for editing or 'erasing' knowledge in Lotus 1-2-3. In the domain representation the edit node is a superordinate node that includes various operators or methods for editing: the escape and backspace keys, and the retype-reenter method (See Figure 1). Because associated links and nodes also receive activation (Collins & Loftus, 1975) from the focused node, we can see in Figure 1 that all three editing methods are partially activated by the question initially. Any new information about the correct method obtained from the response will shift the focus to the referenced node and the new information can be processed and stored in the appropriate area of the activated knowledge structure.

In a hypothetical tutorial dialogue that might ensue, the student could pose another related question and use the new question probe to shift the focus across levels of the knowledge structure and maintain activation in a particular area of the network as tutorial responses are processed. For example, the student might ask about other methods or operators for editing:

Can I use the escape key? (No, but you could use the backspace key.)

Where is the backspace key? (On the upper right corner of the key board.)

In this way, activation moves down from the editing node to its lower-level nodes making these other items available in WM as the student attempts to understand a particular problem. This process of expanding questions surrounding a particular node can be thought of as a form of elaboration. Reder and her colleagues (1986) report that elaborations seem most important to the student learning to select and execute procedures correctly. Following this notion, we can see that student questions as probes in the network may also serve an elaborative function, however, I will not pursue this cognitive process any further here.

Another example of the focusing function is in the case where retrieval processes are unable to transfer the needed information to WM from LTM. In this case, a question can access the knowledge structure, maintain activation at a particular level, and serve as a bridge between the LTM trace and WM. Consider a student who encounters a task goal similar to one accomplished previously but is unable to retrieve the information and asks a question:

I can't remember how to use the point-highlight method.

Through this question the activation spreads through the higher-level knowledge node where this method should be stored, Data Entry, and descends to the subordinate node for the point-highlight method (See Figure 2). In interpreting the question, we can assume the student believes this data entry

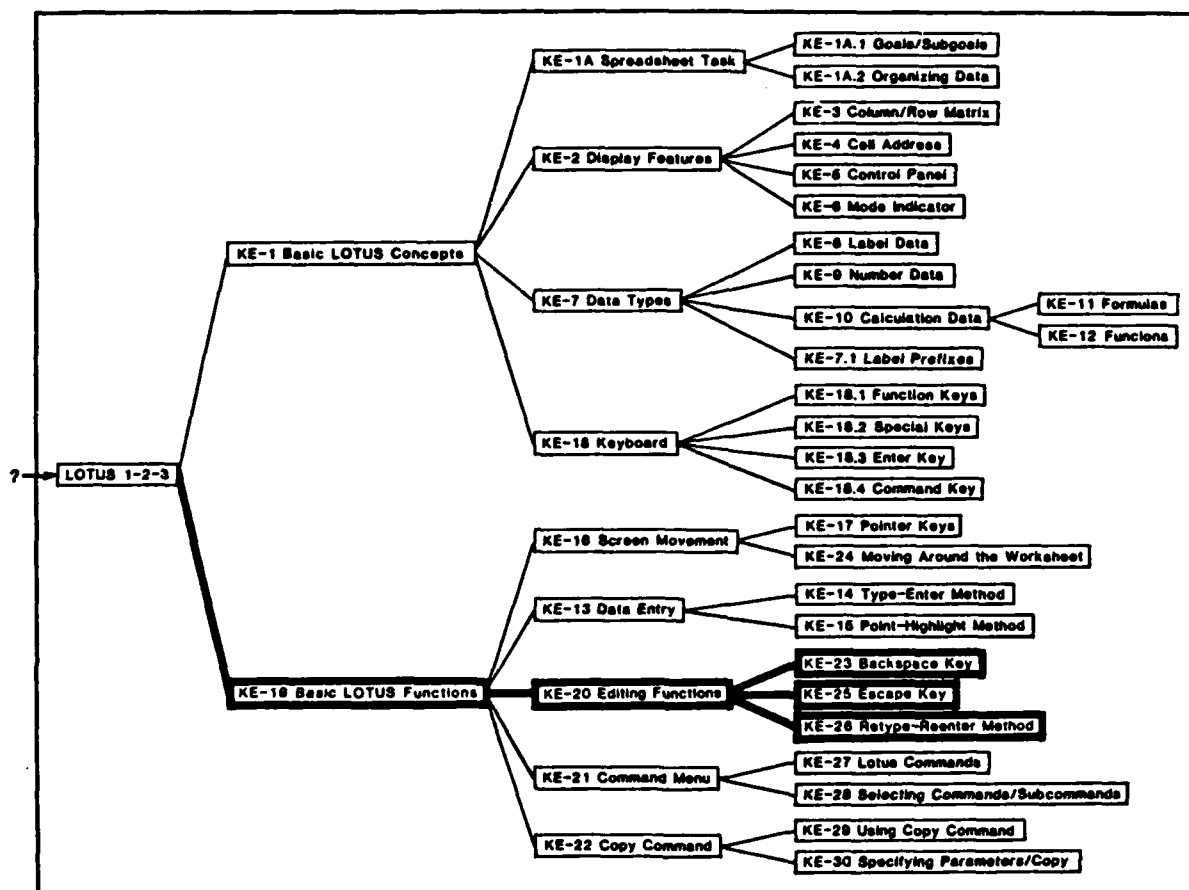


Figure 1. Semantic network model used for tutorial instruction with a Question activating the network

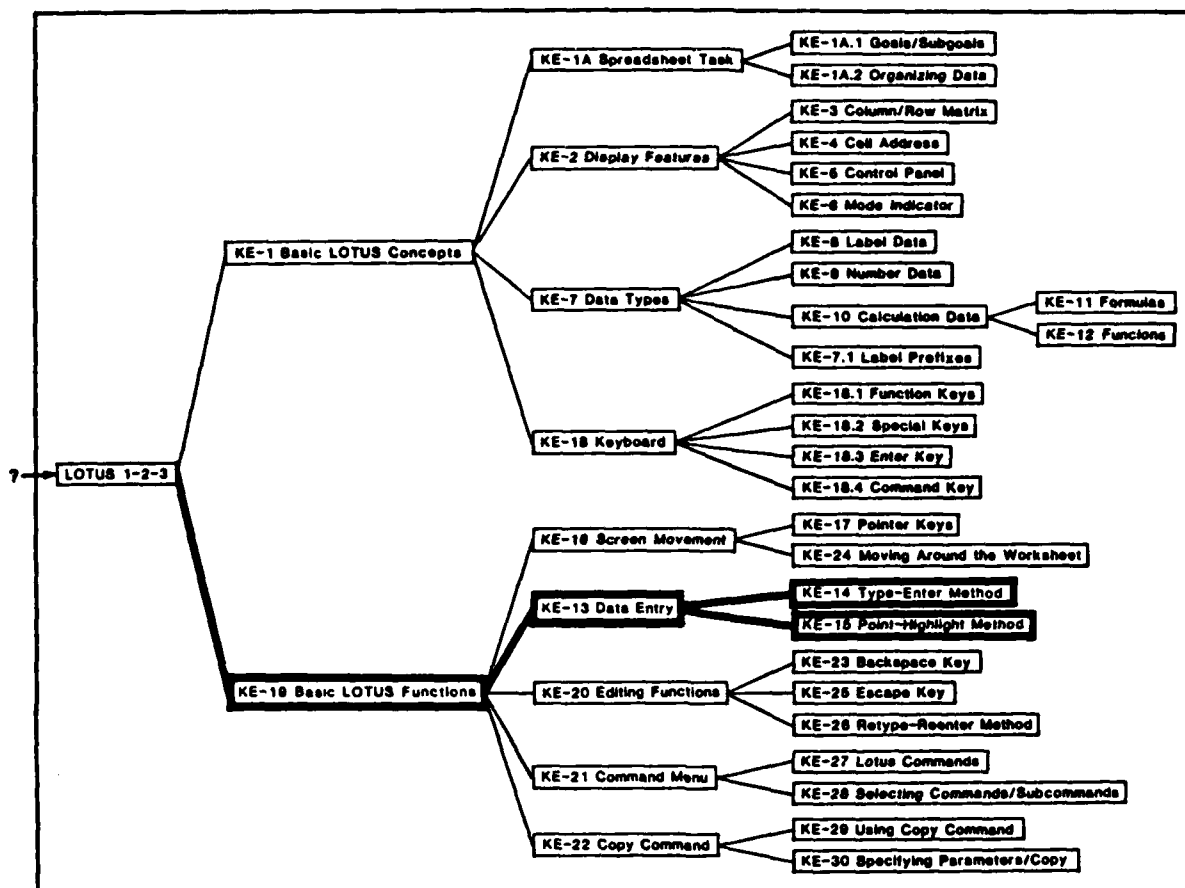


Figure 2. Question activating a lower level in the network

method to be correct and so articulates the need for assistance in carrying out the individual steps for the method. We can infer that the method is not yet instantiated in the domain representation at this stage of acquisition and thus cannot be transferred to WM when needed. Here the question accesses the top level node for the knowledge sought, descends to the point-highlight node, and maintains activation so that the appropriate associated information can be brought into WM as the tutorial response is given enabling the student to carry out the method. With the appropriate response and subsequent student performance, new nodes containing the information necessary to carry out this method will be added and strengthened in the network.

Novice students will have little or very weak associational links between nodes in their knowledge representations initially. Thus, one might wonder why focusing activation would be a critical element for facilitating comprehension of the new material. Nevertheless, there are certain factors that come into play even when the strength of association in the network is not well established. When multiple input sources from the system environment initiate activation in the developing internal representation, students may become confused and cognitively overloaded by these various stimuli. Because the domain is so new and as yet not well organized, students may be unsure of what particular feedback source over and beyond that activated by the task subgoal is important. Therefore, questions may be articulated in an attempt to focus activation on the perceived relevant knowledge.

Consider an example where the student is attempting to apply a multi-step method for entering numbers into an argument range as part of a calculation. The immediate goal is to create the calculation, however, the action required to accomplish this goal generates multiple feedback sources from the computer display which can be confusing to the novice. Feedback from one action prints information on one part of the screen; another highlights a different region as the range is specified. These system responses may serve to increase the level and spread of overall activation during processing of this subgoal. A student may choose to ask a question to focus on one source and consequently control the activation. For example:

Does this highlighted area indicate the cells in the function?

This question serves to focus on one feedback source resulting from specifying this range as the student attempts to understand how this data entry method works. Through such question asking, a student is able to control what is being processed. Now that I have described how questions function to focus and sustain activation in a particular area of the network, we can continue with the second question function of discriminatory and generalization processes to organize and structure knowledge.

Questions as Guides for Organizing Knowledge

Students acquire information through active problem solving, dynamically updating the representation for the knowledge through repeated practice. Reactive environments which inform students of their success or unsucess as they solve problems serve to foster this type of learning. As students reason about the new knowledge being learned, they may engage in

discrimination or generalization learning. Certain types of pedagogical questions articulated at specific times within the acquisition process can reflect these types of learning as students evaluate their knowledge state with the current task state. As the knowledge becomes instantiated in the student's internal representation, questions will function to organize and strengthen a particular aspect of knowledge that is being learned (Swartz, 1987; Robertson & Swartz, 1987). In contrast to the activation focusing function, only certain kinds of questions function to organize the knowledge. Since all questions accessing the domain knowledge function to focus activation at a particular location in the network, organizing questions will have a dual functionality.

Performance feedback that is not understood will direct the questioner toward a certain path in memory dependent on the active problem space in which he or she is interacting by providing the student with information to evaluate and match with what is currently in the knowledge structure (Collins, Brown, & Newman, 1987). When students compare this feedback with their own expectations of the consequences of a particular action, they may choose to ask a question to confirm these expectations. In much the same way, the instructional sequence will provide the student with situations with which to evaluate what is currently stored in memory. The particular time within an instructional sequence that a question is posed will define search control in the representation based on the completeness of the knowledge structure, what is known about the goals, operators and methods or the level accessed in the structure, what needs yet to be learned, and the strength of association for the knowledge or how well it is learned. As learning proceeds through the associational stage, pedagogical questions will function to organize the knowledge.

As novice students encounter and attempt a new problem, they generally focus on localized evaluations of immediate consequences of their actions (Anzai, 1987). When novices compare their condition-action states, discrepancies are often noted because of student error in applying a particular action or misconceptions they may harbor. Learning by doing promotes exploratory behavior and students will often apply problem solving strategies when a task subgoal cannot be met because the skills are not yet acquired. At such times when their problem solving strategies do not help them exit the 'impasse' (Brown & VanLehn, 1980) the student may choose to ask a question. This identifies the student's inability to find a correct repair solution as the motivational basis for question asking. The state evaluation process in this instance can be used to discriminate between the differences observed and those expected through articulation of some type of question intended to clarify the situation. As search control is altered by feedback and continued learning and practice, so too is the function for the question. Questions may serve to discriminate between states initially and later on to generalize about the knowledge as students attempt to understand what they are learning.

Discriminatory Questions

In learning research, discrimination learning can be defined as comparing differences between positive and negative exemplars (Anderson, 1983a) which are subsequently used by the student to evaluate and properly encode the

correct conditions for applying some sequence of operations. A difference heuristic is applied to the states being compared that isolates discriminant features between them (Carbonell, 1987), and this information is subsequently used to reorganize the knowledge stored in memory. Consider some examples where students encounter situations where the consequence of their problem-solving strategies (a negative instance if it's errorful) do not match with the desired condition (a positive instance). As the student evaluates and attempts to understand the reason for the discrepancy, he or she may articulate a question to aid comprehension of the detected difference. This question will function in a dual role: to monitor learning via discrimination and to solicit instructional feedback to explain the discrepancy.

Questions functioning as discriminators during skill acquisition will take on context-specificity depending on what type of information the student is evaluating and the nature of the condition-action consequences resulting from the student's problem-solving behavior. Thus the particular state a student is confronted with will define the context. For example, a student learning computer applications can press a wrong key thus resulting in an erroneous state. Attempting to understand the discrepancy between the state anticipated by the action and the actual state that resulted, the student may pose a question:

Why is that symbol printed there?

In this case, instructional information is solicited and once the tutorial response is received, the student learns that an error has been made. (Why questions comparing two states or a sequence of actions are indicative of seeking causal information). With this explanatory information, the student can correct the mistake, move forward in the task, and appropriately encode the unit of knowledge. Consider another situation where the student is learning a method for executing a copy command. The method requires that certain operations be conducted in a specific order. The novice student has mistakenly applied these operations in an incorrect order resulting in a state which was not anticipated by the student. As the current state (negative instance) is compared to the intended state, (positive instance) that the student has in his representation for the knowledge, the student may pose a question to evaluate the discrepancy.

Shouldn't that have copied the cell?

Again, the instructional response solicited will point out the correct sequence of operations required by the method the student wants to use. In this question, a verification type, an implied hypothesis is asserted suggesting that the student expected the copy behavior to have occurred. Previous work in pedagogical question asking (Swartz, 1987) has noted that a sequence of casual-verification type questions suggests that students are forming and testing hypotheses about states as they are evaluated. Thus, as students monitor their own learning, these questions can facilitate discrimination learning while actively acquiring problem-solving skills. Another way students reason about the knowledge they learn is through an inductive process of generalization. Student questions, especially the casual-verification types, can also be used to articulate generalizations when evaluating states.

Generalizing Questions

Questions that function to generalize knowledge are articulated when commonalities between the current and prior conditions are located and evaluated. In generalization learning, the positive exemplars encountered are regarded as true for all cases until a situation occurs where a particular condition-action state doesn't match the positive instance. Implicit in this type of learning is that a certain amount of knowledge is currently available to enable recognition of positive exemplars. Consider again a student learning the copy command. On encountering a task subgoal, the student may recognize a condition where he or she thinks the copy command may apply. A question to verify this generalization hypothesis may be asked:

Can I use copy on this column if I want it (column of data) to go over there?

Providing that this generalization is justified, a confirmatory response will validate the student's hypothesis. We can infer from this type of question that the student believes the implicit hypothesis articulated to be true (a generalization for the application of the copy command from a different exercise), but is not completely certain and seeks confirmation of this generalization through a verification question. With a confirmatory response, the student can move forward in the task and correctly process the information. If on the other hand the correct response, "No", invalidates the hypothesis, the student will evaluate the negative instance and stop the generalization with the knowledge element he or she is processing through the question. Consider another situation where a student is learning a method for executing the same command. The method requires that certain operations be conducted in a certain order. The novice student has mistakenly applied the operations in an incorrect manner resulting in an incorrect and unanticipated state. As the current state (a negative instance generated through error) is compared to the intended state (a positive instance) the student may pose a question to guide understanding:

Shouldn't that have copied the cell like before?

Again, the instructional response the student is soliciting will point out the correct sequence of operations required by the method needed to obtain the task goal. The negative form of the verification question implies that the student believes the generalization for copying to be true. Indeed, this is a valid generalization if no error were committed. With this error pointed out, the student can now recognize it as such and the generalization for the knowledge can remain intact.

Following Anzai's (1987) claim that novices focus on local consequences, it seems reasonable to expect questions to function for discriminatory purposes prior to generalization in the early stages of skill acquisition. In order to generalize, one needs to have a more established representation for the knowledge and to know about the positive exemplars for a particular knowledge element. Extended learning and practice to develop and organize the knowledge seems a logical prerequisite to this generalization function

for pedagogical questions. Thus the use of generalizing questions will be indicative of students with a certain amount of learning and practice in the domain.

We have seen through these examples how student-generated questions function to focus and maintain activation as the knowledge structure is accessed to bring information into WM. The knowledge activated in the network is then made more available for students to process as the second question function to organize and structure knowledge through discrimination and generalization processes occurs. The last section in this report proposes a method for deriving knowledge states using the theoretical framework for pedagogical question asking as its foundation. With the description of the pedagogical question system and how questions function to access knowledge to process and organize knowledge in memory, we are now ready to describe a model for knowledge state assessment through question analysis and computation of the activation patterns generated from mapping questions unto the domain representation.

KNOWLEDGE STATE ASSESSMENT

Evaluation of the kinds of questions asked during learning should provide information that is descriptive of the knowledge state for a student as the skill becomes acquired. We have seen how students evaluate their own knowledge states prior to asking a question in a monitoring process in an attempt to understand the knowledge. It follows that we might use the sequence of these questions and the activation patterns that result to describe what the student knows.

In the theoretical description of pedagogical question asking I have proposed, the spreading activation framework in memory dictates which nodes in the knowledge structure will be activated when the question is asked. What is sought from the knowledge structure will be identified by the particular knowledge node asked about. Specific information a student needs about that knowledge will be reflected in the type of question utterance that is used. The question interpretation process used to identify question types is made up of a three part symbolic representation for the surface structure of the utterance that defines the form of a question to include the purpose, context, and content. Thus by keeping track of the questions and tabulating the interactions between them and the particular knowledge node accessed, we can derive a model of the student's knowledge at any time during instruction.

Student Model Parameters

The model of a student derived from pedagogical question asking must take into account several factors if it is to be a reliable measure of a student's knowledge state. It must include what the student knows and does not know about the domain, the context of the question, its purpose, and the plan to achieve task goals. Modeling a student's understanding of some subject matter is conceptually related to the definition of the domain representation itself (Burton & Brown, 1979). The question interpretation model I propose is based on a conceptual definition that includes slots for referencing the

domain knowledge asked about, the task context, and one which describes the predicate relation for the question type. (See Swartz, in preparation_a, for more details). Knowledge state assessment can be defined by considering four parameters for the questions in the learning task:

- 1) Purpose of the question (GOALS)
- 2) Location of the question in the instructional problem space (CONTEXT)
- 3) What knowledge is requested (CONTENT)
- 4) Student performance used to achieve task goals (PLANS)

Sources of information to describe a student's knowledge state in computer-based learning can be implicitly inferred from student problem solving behavior and more explicitly inferred from the questions a student asks. The formulation of student knowledge state assessments will result from analysis of the tutorial dialogue that occurs in an instructional sequence and inferences drawn from interpreted questions in view of the four parameters listed above. (Student plans inferred from question asking will not be addressed here in detail, however, Robertson and Swartz (1987) examine this topic further.) The temporal placement of a question when matched with the student's performance behavior and their sequence in a task exercise can indicate a student's plan. They can also indicate when he or she has reached an impasse in the attempted plan and attempted repairs (Brown & VanLehn, 1980) when subgoals are not attained.

The kinds of information necessary for a comprehensive student model might include such items as performance levels for mastery, number of errors, time on task or number of attempts per lesson, to name a few. Information derived from the questions a student asks alone cannot address all the areas above, but in combination with a more complete modeling system for student performance, should provide for a more rich representation of the student model. Student questions in conjunction with student performance will provide the tutor with student feedback that is necessary for more accurate modeling to occur and subsequently better tutoring and instructional delivery.

By mapping the symbolic representation of the student's questions on the knowledge representation and calculating the subsequent activation patterns, we can derive a model of that student's current knowledge state, and from this information, one may be able to infer what concepts and skills are attained or if any misconceptions exist. While it may be tempting to view this knowledge state model as a diagnostic technique, the fact that the usage of this linguistic system varies widely among individuals may affect its general diagnostic utility. Nevertheless, when questions are asked, we want to be reasonably certain that a particular knowledge state assessment is valid as inferred from the question interpretation process. Certainly in combination with other diagnostic techniques in tutoring systems, this model should provide data that is informative of what a student does and does not know.

Question Interpretation

Question decomposition derived from this interpretation model will result from a surface structure analysis of the question utterance and provide a symbolic representation for the functional components that reflect its semantic purpose. Each question phrase is analyzed by identifying the interrogative pronoun and placing it into a conceptual category to reflect the relation function of the question: causal, procedural, property and so on. These 'predicate' relations can be thought of as defining the link types used to associate the knowledge in the domain network representation. The propositional unit is the remainder of the sentence after the interrogative pronoun is removed. This propositional unit is divided into two functional components, the first of which is categorized into a number of classification types to reflect the instructional problem space context encompassing the proposition. The second component of the proposition is the unknown element of the question or what Graesser and Black (1984) term a knowledge element. The knowledge element refers to the instructional content the questioner needs to have to complete understanding. The general model proposed for analyzing pedagogical questions begins with a decomposition for a question into the following three-place form. The predicate relation connotes the primary question function and takes two arguments: context and content.

(<Interrogative Pronoun><Propositional Unit>) -->

(<Predicate Relation><Propositional Context, Knowledge Content>)

Question Goals: Classification of the Question Type

The purpose of the question can be inferred from what kind of information is requested. While the goal of each question at its most basic level is intended to obtain instructional information, according to the first principle in the structure of the general question system, the specific type of information asked for more explicitly articulates the question goal. Although the best expressed goal for each question requires consideration of all interpreted components of the question, we can still obtain the overall purpose of the questions using the predicate relation categories. In linguistics and artificial intelligence research (Grice, 1975; Pollack, 1985; Lehnert, 1978) semantic and conceptual categories have been used to define question predicates (nominal, causative, agentive, procedural, etc.). These predicate types can serve to connote the function or purpose of a particular question for obtaining specific kinds of information. By extension, interpreted predicate relation types identify basic question goals. A student wanting to know the cause of some action or consequence will ask a 'Why' question thus inferring a causal goal. Similarly, a need for structural feature information implies a property goal for 'How much/How few' questions.

The first level decomposition defining predicate relation categories takes the following form:

(<Interrogative Pronoun><Propositional Unit>) -->

(<Predicate Relation><Propositional Unit>)

I adopted a conceptual scheme (Lehnert, 1978) for interpreting the meaning of these interrogative pronouns. For reasons of parsimony and based on preliminary empirical evidence from a pedagogical domain (Swartz, 1987), this portion of the model has been modified and reduced to seven conceptual entities for interpreting the question types used in procedural skill learning and an eighth metacognitive relation. The categories and their matching interrogative pronouns are listed below:

<u>Predicate Relation</u>	<u>Interrogative Pronoun</u>
1. Goal	What, Why
2. Procedural	How
3. Causal	Why
4. Verification	Can, Do, subject-verb reversal
5. Concept Completion	What, When, Who
6. Property/Attribute	How + a quantifier (many, few)
7. Spatial Orientation	Where
8. Metacognitive	(varies-used for rhetorical questions where no response is needed)

The next element in the interpretation model is the analysis of the propositional unit which is classified into a problem space context surrounding the proposition in the question.

Question Context: Classification of the Propositional Unit

When a question is articulated, within the instructional sequence or problem space for the task, will identify the context of the query. In discourse, propositions express the main idea a speaker wishes to communicate. However, the interpretation of questions asked in a situated, reactive environment such as computer-based learning, the immediate environment and its features more so than discourse features will be used to define the context in which the proposition is uttered. Thus, in further decomposing the propositional unit expressed in the question, the model takes on an additional part to describe the context:

(<Predicate Relation><Propositional Unit>) -->

(<Predicate Relation> <Problem Space Context>)

The context classification process depends on the immediate situational environment the student is in when the question occurs. Because the learning paradigm used to assess this interpretation model fosters problem solving strategies as the student learns by doing, these contexts can be viewed as problem spaces. The identity of the problem space context in conjunction with the problem identification process a student undergoes prior to uttering a question, principle 3 in the general structure of the question system, will help interpret the overall intent of the question. Goal space contexts include questions about task goals and subgoals. Action space contexts include questions that refer to operators, operations or a sequence of actions required to accomplish a specific procedure or goal. The third classification type selected is a state space context since problem solvers are constantly

evaluating states as they search for the correct solution path. State space contexts refer to any question about a state transition that results after some operator has been applied to some existing or current state, a particular goal has been obtained or some system state has resulted. Since there may be a merging of two kinds of knowledge in this task, the domain knowledge of the command language itself, and the device knowledge for the computer system, learners may have questions that refer to a particular state transition that could be part of either system.

A set of simple rules is provided (Swartz, in preparation) that will help classify the proposition into these problem space contexts. The temporal placement of the question is used to determine whether the active problem space context that surrounds the question is a goal, action or state space. Although the interpretation model relies on a semantic representation for the surface structure for the question, syntax, and verb tense are used to infer context classification. Once the problem space context is identified, the last element in the model can be classified.

Question Content: Classification of the Knowledge Node

The third element in the interpretation model is the knowledge node accessed in the student's internal knowledge representation for the new skill. This knowledge sought through the student questions will indicate which part of the knowledge representation is accessed or the content. The last element in the interpreted frame is thus added:

(<Predicate Relation><Propositional Unit>) -->

(<Predicate Relation> <Problem Space Context, Knowledge Content>)

As the representation grows and acquires more levels and detail in its structure, the content asked about should access different levels in the network. As the student learns, more information is acquired and a domain dependent organization for the knowledge takes form and develops a more elaborate structure. The level of completeness for the structure will effect the level of search when a question is formulated. Several examples will illustrate how questions can probe various levels of the knowledge structure based on the particular knowledge content sought. See Figure 2 to illustrate the levels accessed.

How do I use the copy command?

(<Procedural><Action Space, Copy Command>)

In this case, the entire list of arguments related to the knowledge node for 'copy command' is unavailable to the student. Thus all steps in the copy procedure are requested in this question implying that the top level node for copy command only is accessed.

What do I do (in 'Copy') after I point to the first element (in the range)?

(<Concept Completion><Action Space, Specifying Parameters/Copy>)

In this case, only some of the arguments are requested through the question. We can assume by the question that the student knows how to access the menu, select the command, and point to the first element, but fails to retrieve the next step in the procedure. Here, the information missing can be thought of as part of the set of elements or leaves descending from the knowledge node for the Copy command.

From these examples we can briefly see that different levels of the domain representation in memory are searched based on what the question asks about. In the first question all of the arguments of the propositional unit in the question 'use the copy command' are missing. The knowledge node asked about in this question requires that all of the leaves in the set of elements that make up the proposition for expressing the procedure for using the copy command are requested. The second question illustrates a question similar to that expressed in the first example, however, only some of the information is requested. We might infer from this question that the person has access to the preceeding arguments related to using the copy command, but is missing the particular step required for anchoring the range.

Question Plans: Location in the Instructional Sequence

By tracing a student in the instructional sequence, we can view the student's questions in relation to the level of knowledge obtained through instruction and the strength of association for the knowledge through amount of practice. The question, along with the performance behavior exhibited, will indicate what solution strategies a student is attempting and any attempts to repair (Brown & VanLehn, 1980) them during skill acquisition. This performance data can provide information about the student plan for accomplishing task goals. Changes in the kinds of questions asked, the particular goals, operators, and methods a student is applying to solve the task problem, should reflect changes in his or her plans.

Novices in any domain would not be expected to ask questions about skills or information they don't know about. Because student representations may not yet appropriately match the conceptual domain structure, their questions in the beginning may even be inaccurate. This notion was suggested in the possible violation of principle 3 (problem identification) in the question system. Thus student plans inferred from question asking may reflect inappropriate or incomplete plans in early phases of skill acquisition.

As an example of plan inferencing from questions, consider the implicit plan of action from the questions below. After a 30 minute tutorial, we can assume that N concepts, procedures, etc., have been presented to the student. The student's performance behavior in the task is used to identify the current subgoal, creating a function. This will be the first item in the student's plan. As the student begins the plan, a question is asked:

How do I use that point-highlight method?

(<Procedural><Action Space, Point-highlight>)

At this point, we can infer a second step in the plan: using the identified method (point-highlight) for obtaining the present goal of creating a function; an appropriate method in this case. Furthermore, although the student has indicated through the question that a correct method has been selected, he or she also indicates that assistance is needed in order to carry out the plan of action. Additional questions to assist in accomplishing the current subgoal can also be used to infer steps in a plan. Assume the student had not mastered all the steps required to accomplish the method. During execution of the current plan, he or she may ask:

Do I point now?

(<Verification><Action Space, Pointer Key>)

At this point, the tutor can evaluate the plan based on student performance leading up to the question and provide an appropriate response. If, given the current goal and plan, this question were inappropriate, the tutor could respond accordingly and help the student revise his/her plan plus correct the knowledge that the student is assimilating into his/her internal representation. Weights for the level of knowledge and amount of practice (see below) can be added to the appropriate subgoal to aid in tracing a plan.

From the interpreted questions alone we are able to identify three of the four parameters necessary for modeling the student: goals, context, and content. Student plans inferred from question asking assumes a more sophisticated modeling system capable of tracing student performance and will not be addressed any further here.

Activation Patterns for Knowledge State Assessment

Activation patterns in a network when calculated from question probes at specified intervals will reflect which nodes are being currently activated and brought into WM for processing. Level of knowledge is measured by quantifying the number and type of instructional task goals a student encounters in an instructional session. Strength of association is measured by several factors: the number of exercises the student has attempted, the reoccurrence of similar task goals, and what knowledge is being questioned. Weights can be added to the appropriate knowledge nodes to compute the accretion resulting from these factors. The temporal placement of the question will demarcate where the student is within the instructional sequence. By matching this placement to the student's present level of knowledge and strength of association, we will be able to identify how much knowledge the student has in his or her internal representation and what organization it has as compared with the conceptual representation used in the figures in this report.

Use of Anderson's (1983b) spreading activation framework will allow me to discuss the thesis that questions serve to organize knowledge, build associational links, and strengthen new information brought into a developing knowledge representation. I hope to provide a mechanism by which we can assess how knowledge structures come to be constructed during learning with

the aid of question asking. I do not want to make claims about any particular activation theory, and use this framework only as a vehicle for the presentation of the ideas I wish to express.

Practice and Node Strength in the Network

Spreading activation assumes that activation moves through the network providing a constant but varying pattern of activity reflecting the association and strength of the links and nodes. WM can contain traces from LTM and can receive links to traces from LTM through question-triggered activation. I have presented how questions can function to focus activation in a network, thus serving as a bridge to the LTM trace when information is brought from LTM to WM. Anderson believes that a pattern of activation in LTM is set up in response to the activation accumulated from what he calls focused nodes. I will refer to these focused nodes as those whose activation is triggered through question asking. The level of a node's n_y total activation can be derived from its activation a_{1y} to a_{iy} received from nodes n_1 to n_i yielding a basic summative equation $\sum a_{iy}$ for node n_y . Activation that a node n_y sends through a network is defined by the strength of each of the connected nodes n_1 to n_i and activation level for the node initiating activation. Relative strength for the node must be determined as well as loss of activation through decay. The level of activation for a node a_y is derived using the formula below:

$$a_y = \sum f_{xy} a_x + a_c + q_y$$

See Anderson (1983b) for a more complete discussion of this model and the supporting equations. Here q_y is 0 unless it is a focused node represented by a question asked in which case a value indicating the amount of activation emanating from the question would be assigned to q_y and added to the equation. The constant source of activation, a_c (where a task subgoal is being processed), will have a value if present. If no constant source is present, a_c will be 0 and only the activation from the associated nodes will be entered into the equation ($\sum f_{xy} a_x$). Thus this equation should reflect the pattern of activation resulting from the questions as activation focusers in addition to the constant source, a_c , for a node. Another factor central to this framework is that the strength of a node is a function of its frequency of exposure. Following Anderson's model, I assume that the strength of the focused nodes determines the amount of activation emitted into the network. Consequently, the stronger the node, the greater the activation. Anderson offers an equation for summing the total strength of a node,

$$S = \sum t_i^{-b}$$

The time since the i th strengthening is t_i . Practice in a task will improve performance and strengthen the associations in the student's internal representation, thus we can view this effect through the following equation.

$$S = \sum s(it)^{-b}$$

where s is assumed to be spaced repetitions for t time units apart. The strength of each repetition is s and $b(<1>)$ is the exponent of the power function.

Calculation of Activation Patterns

The following example in Figure 3 using a portion of the conceptual network representation for the domain will illustrate the activation received from a question in relation to the strength for the accessed node. Consider a student faced with a task subgoal of entering a label, BRIDGE, into the spreadsheet. This data entry subgoal will serve as the constant source of activation while the student is working on this task. I assume that the student has selected the type-enter method (KE-14 node) as the appropriate data entry procedure. This node is assigned an activation level of 1, a , for constant source. The student asks a question, "How many spaces are in a cell?", and the activation shifts to the node for cell address KE-4, that becomes the newly focused node. It too receives an activation level of 1, q_1 for the question asked in the activation equation.

The strengths for each node are denoted in the figure by s_i . Since the strength of node KE-14 is 4 and node KE-4 is 2, their current activation levels will take 4 and 2 units of activation respectively. Following Anderson's model, activation is proportional to the sum of the node's strength. This is calculated using the strengths from the associated nodes. Therefore, the relative strengths for KE-14 are $4/8$ (KE-14/KE-4,2) + $4/9$ (KE-14/KE-14,4) + $4/9$ (KE-14/KE-14,13) and for KE-4, $2/6$ (KE-4/KE-4,14) + $2/5$ (KE-4/KE-4,2). The activation from nodes KE-4 and KE-14 will propagate through the network and spread activation to the associated nodes assigning relative values taking into account the distance from the focused nodes and decay.

To illustrate the calculation for the simple activation levels for the nodes in Figure 3, I will first make some basic assumptions. Because activation decays when the node is not focused, I will select an arbitrary value of .5 for the decay factor, d . Calculating activation levels that includes the reverberation construct becomes difficult even in a small subset of the domain network shown here. Therefore, for purposes of illustrating this model, I will assume a direct forward flow of activation. The equation then will reflect the relative strength for each associated node with the decay factor computed.

The total activation for nodes KE-4 and KE-14 is the sum of their own activation (a question or task subgoal as a source of activation) plus the summed activation received from the associated nodes:

$$a_{KE-4} = 2 + 2/6da_{KE-14} + 2/5da_{KE-2}$$

$$a_{KE-14} = 4 + 4/8da_{KE-18} + 4/9da_{KE-4} + 4/9da_{KE-13}$$

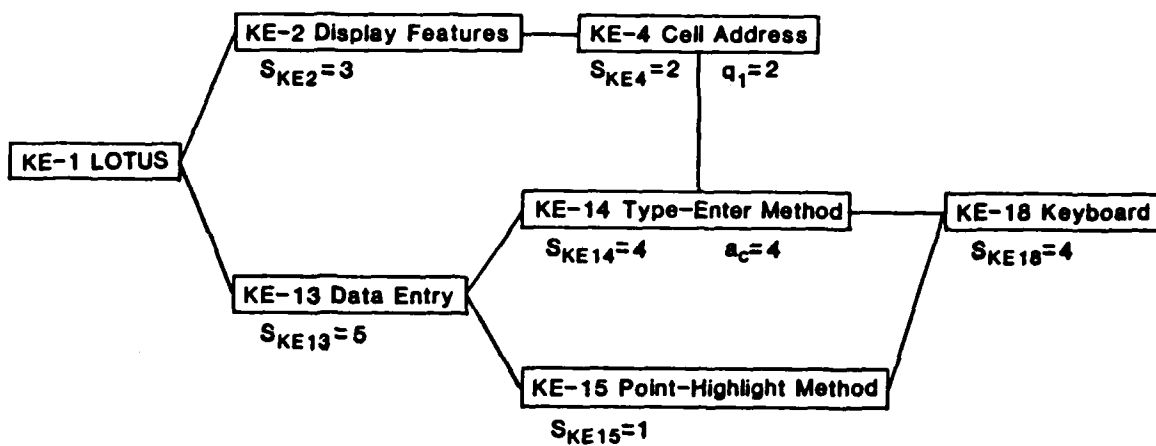


Figure 3. Partial network illustrating the calculation of the simple activation level

In this way, activation levels for all the associated nodes in this portion of the network can be derived. If we add in the decay factor for each of the associated nodes, we get the following values:

$$a_{KE-4} = 2 + (.5)(.33)a_{KE-14} + (.5)(.4)a_{KE-2}$$

$$a_{KE-14} = 4 + (.5)(.5)a_{KE-18} + (.5)(.444)a_{KE-4} + (.5)(.444)a_{KE-13}$$

These levels reflect more accurate activation when accounting for the natural decay emanating from the unfocused nodes. Simultaneous equation solutions give the values of 5.85 and 10.194 for the two nodes respectively. According to Anderson, information from node KE-14 should be retrieved more easily than information from KE-4 based on its higher activation level. I argue that in a learning situation this higher value permits easier access to the information in LTM as it is brought into WM for local processing. By extension, this information, since it is easier to access, would become instantiated first in a given representation.

Summary

Taking a series of interpreted questions from some learning task in conjunction with the task subgoals a student has interacted with, we can calculate the current knowledge state activation pattern by applying the equation

$$a_{y1} = \sum f_{ax} a_x + q_y + a_c$$

to the conceptual network representation used to deliver instruction. By setting a threshold criterion for a strength value, s_i , for each node indicating an instantiated state, the calculation of the activation patterns will reveal which nodes in the structure are instantiated or acquired at a given time. If the strength value for a particular node is below threshold, its strength will be the sum derived from the total sum equation, $S = \sum (it)^{-b}$.

Each time a particular subgoal representing a knowledge node is presented to a student within an instructional sequence, a weight can be assigned to that node strengthening its place in the knowledge structure. Similarly, each time a question is asked a weight will be assigned to the appropriate node. These weighted values can be used by the student modeler to determine knowledge state assessment based on number of times a particular knowledge node has been presented to the student and the number of questions asked per node. As new knowledge nodes are presented and instantiated in the student model, the knowledge representation derived from the activation pattern will take on more levels in its structural makeup. Work is underway to assess this methodology using the two parameters, a_c and q_y , for deriving knowledge state activation patterns.

CONCLUSION

The proposed question model described in this paper is intended to provide a basis for further investigation into the cognitive processes that underlie question asking and the usefulness of this model for describing a student's knowledge state. Pedagogical questions function as a control mechanism to focus and maintain activation of knowledge in the network during

learning. As a second function, these questions serve to make explicit the discriminatory and generalization processes a student is engaging in as information is organized, evaluated, and strengthened in the student's internal representation. The spreading activation framework as the foundation for understanding how these questions probe memory will permit researchers to investigate the relevant issues for how and where the knowledge is accessed and represented as the domain structure is generated.

I have argued that students ask questions when they have identified a problem (not having access to the needed information) or when their repair solutions (Brown & Van Lehn, 1980) fail during problem solving. From the model described here and these two arguments, it is clear that students must access memory prior to articulating questions. Through the computation of activation patterns generated from question asking and performance behavior at various stages of skill acquisition, we can graphically describe a student's particular knowledge state. By identifying what level of knowledge is accessed and how these activation patterns change over time, we will be able to trace the development of a student's internal representation for the domain knowledge. These changes will thus offer evidence in support of the idea that knowledge representations change qualitatively as learning increases (Hayes-Roth, 1977), and, the identified levels from a particular knowledge state should be useful for predicting the kind and number of questions students ask (Miyake & Norman, 1979).

Understanding the question subsystem and how it operates in pedagogy may also have important implications for providing tutorial feedback in military training systems. We have seen that the pedagogical question system is a specialized communication subsystem which operates according to general conversational rules as well as its own unique set of principles for optimal functioning. This communication subsystem serves the purpose of exchanging instructional information between student and tutor. Analysis of the questions military students ask can help the tutor to identify what particular concept or skill a student is processing at a given point in time. With this information, precise, more adaptive tutorial responses can be provided to individual students. This instructional feedback will serve to guide military students in better comprehension of what they are learning and enable the tutor to correct any misconceptions that these students may have formulated. Similarly, this feedback should help military students in their problem solving strategies in a learning by doing environment. When soldiers are able to pose their own questions in the learning task, they will be able to control instructional delivery according to their individual needs. Finally, the knowledge state information derived from the activation pattern calculations may be useful for student modeling in computer-based learning to identify what a student knows and does not know. However, the student modeling problem is a very hard one to solve and it is unclear at present how useful the question asking data alone will be in the absence of more sophisticated modeling techniques.

Current psychological research is beginning to examine this model of question asking as a first step toward understanding the cognitive components involved in student question asking. This work (Swartz, in preparation_o) will attempt to provide evidence in support of the theory of pedagogical question asking so that we may understand how this metacognitive

process facilitates knowledge acquisition. Future work is planned to assess the usefulness of calculating activation patterns in order to define knowledge states. Only when we can understand what information students request and how their questions access knowledge in memory can we begin to understand how student question asking in tutorial dialogues functions to facilitate learning. This research problem is a difficult one; the proposed model is a first attempt toward solving it.

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